

# Open-Loop Receiver Recording for Telemetry Data Recovery: A Field Demonstration

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*During a normal scheduled track of Pioneer 11 at DSS 12, open-loop receiver analog recordings were made of the spacecraft signal. These recordings were later played back at the Compatibility Test Area using an up-converter to provide an S-band input signal to the normal telemetry string. The results of this demonstration show a telemetry loss of 0.9 dB based on average symbol error rate values.*

## I. Introduction

During a normal scheduled track of Pioneer 11 on May 22, 1975 at DSS 12, open-loop receiver analog recordings were made of the spacecraft signal on a non-interference basis to real-time telemetry reception. A Block III receiver, configured as an open-loop receiver (OLR), heterodyned the S-band carrier down to 174 kHz for recording on an Ampex FR-2000A recorder operating at 76 cm/s (30 in./s). Two recordings, each approximately one hour long, were made of the Pioneer 11 signal. During the recording period, the real-time telemetry string (represented by the other Block III receiver, subcarrier demodulator assembly, symbol synchronizer assembly and data decoder assembly configured as a 32-bit constraint length, rate 1/2, convolutional decoder) provided symbol error rate (SER) statistics on decoded bits (256 bps) and frame erasure data to the digital instrumentation

subsystem (DIS), which provided a printout of the SER and frame erasures.

In early June the two recordings were played back at the Compatibility Test Area (CTA 21) using an up-converter to provide an S-band input signal to the telemetry string. The digital instrumentation subsystem provided SER statistics on decoded bits and frame erasures during the playback. Playback was accomplished on an Ampex FR-2000A recorder operating at 76 cm/s (30 in./s).

## II. Configuration

Figure 1 is a block diagram showing the telemetry string configuration for the demonstration. Receiver 2 was used as the open-loop receiver on a non-interfering

basis to real-time telemetry reception in receiver 1. The digital instrumentation subsystem was loaded with Monitor III Program software.

Figure 2 is a partial diagram of the Block III-C receiver showing how the telemetry B string channel was configured to provide a low-frequency IF output to the analog recorder. To operate as an open-loop receiver, the phase-locked loop was disabled by "shorting out" the output of the loop filter. The voltage-controlled oscillator, then, was capable of being preset to any desired frequency by means of the manual frequency control voltage. The two blocks in Fig. 2 shown in dashed lines are not a part of the normal receiver. Since the selectable band-pass filter has four preset bandwidths, the variable band-pass filter was employed to minimize the noise bandwidth so as to maximize the signal-to-noise ratio in order to assure sufficient signal level for up-conversion without fear of noise limiting in the playback process.

The single-sideband (SSB) mixer (Ref. 1) is necessary to reject the image noise occurring below 10 MHz. The output frequency response of the SSB mixer is from 100 Hz to greater than 2.0 MHz, with the unwanted image noise reduced by more than 20 dB.

Figure 3 is a block diagram of the up-converter used to convert the low-frequency signal up to S-band for processing through the normal telemetry string for data recovery.

Figure 4 is a simplified diagram showing the configuration employed at CTA 21 during the playback of the tapes recorded at DSS 12 (Goldstone).

### III. Recording/Playback Technique

The basic technique described herein was originally reported in DSN Progress Report 42-20 (Ref. 2), which presented results of tests performed at CTA 21. For those particular tests, an Ampex FR-1400 analog recorder was used to record the signal, and an Ampex FR-2000 analog recorder was employed during playback. Because of the poor instantaneous stability of the FR-1400, a time jitter compensator was used to limit the data degradation to an acceptable level.

With the advent of the newer generation analog tape recorders, such as the Ampex FR-2000A, it was determined that time jitter compensation was not necessary to achieve data degradation less than 1.5 dB due to the recording and playback process.

Thus, without the need for compensation, the recording technique reduces to one of offsetting the signal in the open-loop receiver such that its spectrum falls within the recording range of the analog recorder, adjusting the total power level (signal plus noise) so saturation does not occur, and then simply recording at the proper tape speed.

Playback, then, is a matter of up-converting the signal to S-band and injecting it into the normal telemetry string for data reduction. There are two main concerns: (1) sufficient signal gain without noise saturation, and (2) signal frequency knowledge to insure receiver acquisition.

### IV. Recording Bandwidth Requirements

The Pioneer 11 spacecraft was transmitting a long constraint length rate 1/2 convolutional coded signal at 256 bps biphas-modulated on a square wave subcarrier with a frequency of 32.768 kHz, which was, in turn, phase-modulated on a sine wave carrier with a frequency of 2292.407407 MHz. Due to doppler effects, the actual carrier and subcarrier frequencies received were 2292.210656 MHz and 32.770 kHz.

With square wave modulation, the total data power contained in the received RF signal can be expressed as

$$P_D = P_T \sin^2 \theta \quad (1)$$

where

$P_D$  = total data power

$P_T$  = total RF power

$\theta$  = modulation index

and the power contained in the  $n$ th harmonic ( $P_n$ ) of the square wave frequency is

$$P_n = P_D \left[ \frac{2 \sin \theta}{n\pi} \right]^2 \quad (n = \text{odd numbers}) \quad (2)$$

Since, from Eq. (2), the relative power contained in the  $n$ th sideband is proportional to  $1/n^2$ , the theoretical total relative power ( $P_R$ ) is dependent upon the number of sidebands received, or

$$P_R = \sum_{n=1}^{\infty} \frac{1}{n^2} \rightarrow \frac{\pi^2}{8} = 1.2337 \quad (n = \text{odd}) \quad (3)$$

If only the first three components are received, the power loss is

$$P_L = 10 \log \frac{1.1511}{1.2337} = -0.301 \text{ dB} \quad (4)$$

Assuming the additional bandwidth requirement due to the low data rate is negligible compared to that required for the square wave subcarrier, the minimum recording bandwidth (for 0.3-dB loss) then is approximately 328 kHz.

The FR-2000A recorder, in the direct record mode, has a lower frequency response ( $-3$  dB) of 400 Hz at all tape speeds and on upper response ( $-3$  dB), as shown in Table 1.

In addition to its amplitude limitations the phase response of the recorder is linear only to about 60% of its upper response limit. Based on Table 1 and the recorder phase response, a tape speed of 76 cm/s (30 in./s) was selected for this demonstration. Thus, the anticipated

data degradation due to sideband losses alone were on the order of 0.3 dB.

## V. Data Summary

The monitor program provided a printout of the number of frames decoded, the number of frames erased, and the number of detected symbol errors in the Data Decoder Assembly. Table 2 is a summary of the data collected during the recording of the real-time telemetry at DSS 12 and the playing back of the tapes at CTA 21 on May 30 and June 3. The symbol signal-to-noise ratio (SSNR) tabulated in Table 2 is based on the average symbol error rate.

The average SSNR during recording was 1.85 dB, thus the average SSNR of the playback of 0.94 dB represents a telemetry loss of 0.91 dB.

Frame erasure statistics are deemed insufficient, on such a small data sample, to be used as a good measure of telemetry loss.

## Acknowledgments

The author wishes to thank E. S. Burke, Jr., for making all necessary arrangements to conduct the demonstration at DSS 12 as well as suggesting the use of the monitor software program for data reduction. Appreciation is also expressed to J. R. McAllaster and W. Snow for their expertise and assistance with the analog recorder, to the crews of DSS 12 and CTA 21 for their efforts in gathering and playing back the data, and to M. H. Brockman for technical guidance in this effort.

## References

1. Rogers, A. E. E., "Broad-Band Passive  $90^\circ$  RC Hybrid with Low Component Sensitivity for Use in the Video Range of Frequencies," *Proceedings of the IEEE, Proceedings Letters*, pp. 1617-1718, Nov. 1971.
2. Kent, S. S., and Sleky, A. G., "Open-Loop Receiver/Predetection Recording System for the DSN," in *The Deep Space Network Progress Report 42-20*, pp. 139-148, Jet Propulsion Laboratory, Pasadena, Calif., Apr. 15, 1974.

**Table 1. FR-2000A upper frequency response (−3 dB)**

Tape speed		Response, MHz
cm/s	in./s	
305	120	2.0
152	60	1.0
76	30	0.50
38	15	0.25

**Table 2. Summary of data accumulated during record and playback**

Tape	Frames accumulated	SER average	SSNR, dB	Erased frames
Record				
1	5307	0.041	1.80	7
2	2500	0.039	1.90	0
Playback				
5/30				
1	4400	0.060	0.80	—
2	4534	0.055	1.05	34
6/3				
1	4547	0.061	0.80	47
2	4222	0.054	1.10	22

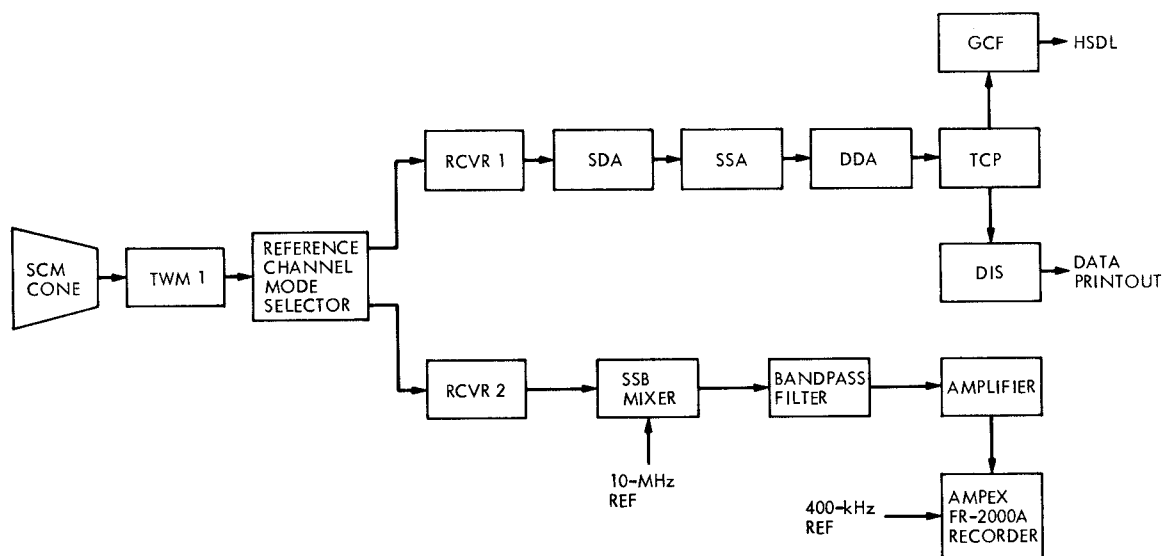


Fig. 1. Telemetry configuration

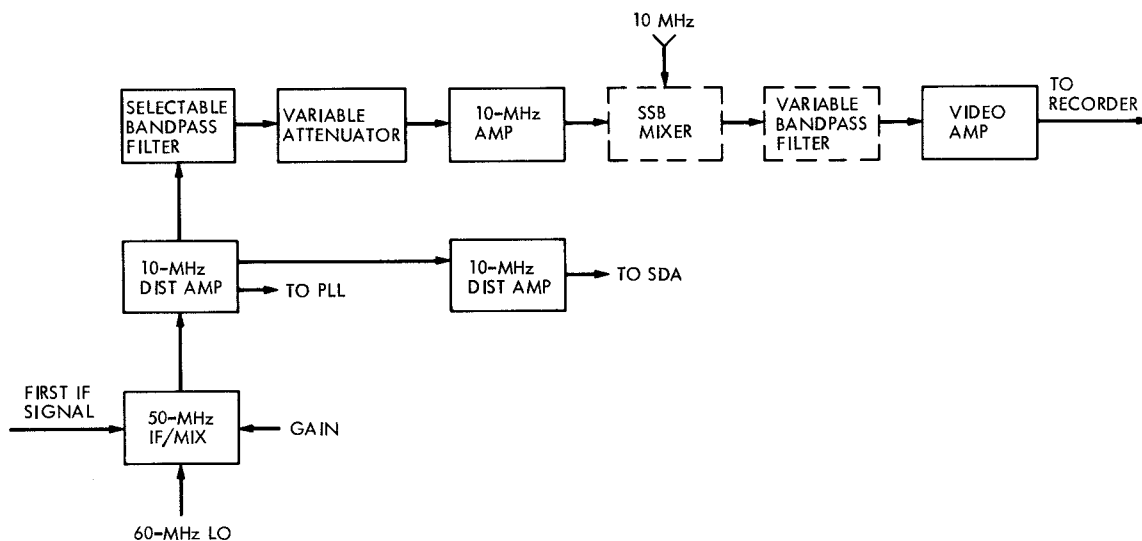
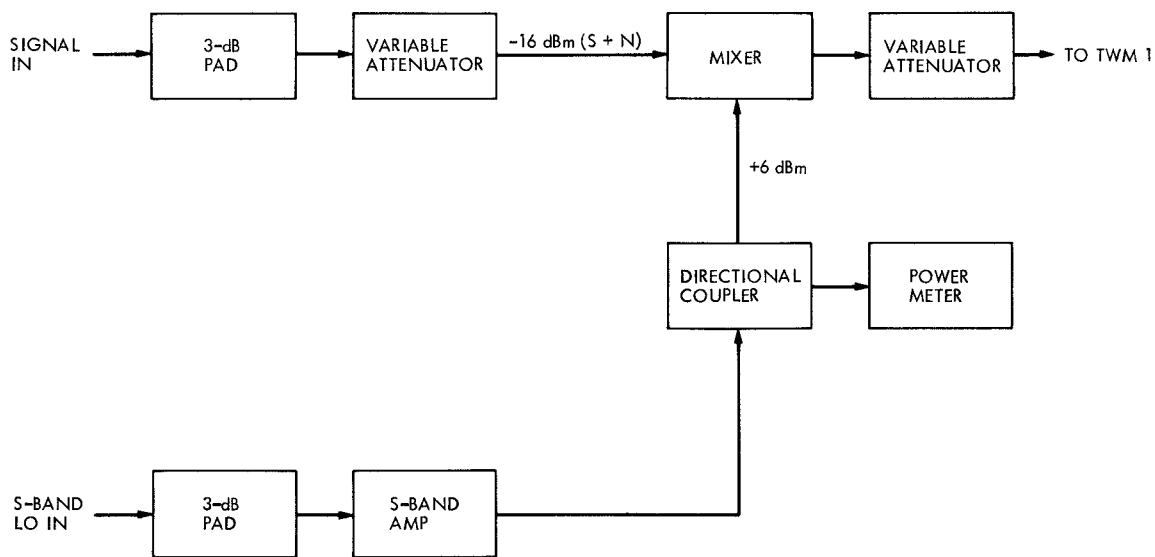
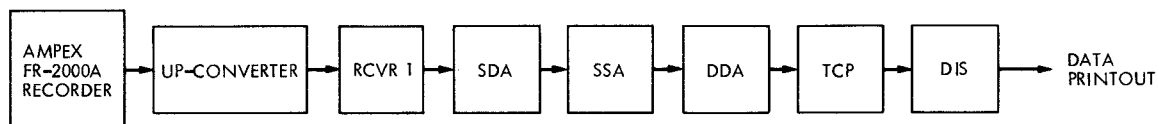


Fig. 2. Partial diagram of the Block III-C receiver showing open-loop configuration



**Fig. 3. Block diagram of up-converter**



**Fig. 4. Block diagram of CTA 21 configuration**